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Agricultural Economics Research

Summer 1985 Vol. 37, No. 3

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A Journal of the United States Department of Agriculture

Economic Research Service

Agricultural Economics Research

A Journal of the U.S. Department of Agriculture • Economic Research Service

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The Secretary of Agriculture has determined that the publication of this periodical is necessary in the transaction of public business required by law of this Department. Use of funds for printing this periodical has been approved by the Director, Office of Management and Budget, through March 31, 1987.

This periodical is published quarterly. Subscription rates are $13.00 domestic; $16.25 foreign. Send check or money order (payable to Superintendent of Documents) to:

Superintendent of Documents
U.S. Government Printing Office
Washington, DC 20402

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In This Issue

Increases in agricultural productivity contribute to national economic development and income growth by releasing labor resources for nonagricultural sectors and by increasing the economic surplus that can be transferred out of agriculture. The transferred surplus provides a basis for economic growth in nonagricultural sectors and also provides foreign exchange if these agricultural commodities are exported.

To illustrate the truth of this nearly self-evident statement, consider what it would mean to this Nation's standard of living if we still needed 30 percent of our workforce on farms, as we did in 1900, instead of the 2 - 3 percent we do now. We would have to forego many nonessential services we now take for granted. Because productivity growth is so important an underlying economic factor in the potential rise in the standard of living, it is no surprise that economists have attempted to measure and monitor productivity changes.

Measuring productivity has proven difficult, both conceptually and empirically. These issues have been debated at numerous professional conferences. Pages of professional journals, books, conference proceedings, task force reports, and the like have been covered with recommendations, debates, and discussions. Yet, not only do we not have a consensus on how to measure agricultural productivity but, as Anne Carter points out, it's not clear that efficiency of individual processes leads to efficiency of an economy. Given this state of the art, identifying and measuring productivity will probably continue to keep economists employed but frustrated.

In the lead article in this issue, Clark Edwards illustrates that, even if you take as objective an indicator of productivity as crop yield per acre, you cannot easily use aggregate data to unequivocally explain higher productivity (yields) because of the interactions among technology, firm structure, and regional crop distributions.

Not only does Edwards illustrate well the pitfalls of using aggregate data to measure and monitor agricultural productivity, but he also provides a measure of how little we have progressed since Christensen and Yee wrote in the July 1964 issue of *Agricultural Economics Research.*

Given the general view that a true productivity change involves a shift in the production function, consider this passage from their article, and mentally tabulate the number of supply and demand forces other than changes in the production function that are included in the present productivity measure you deem most reliable.

"Perhaps the most effective way to analyze the factors affecting agricultural output and productivity is to consider them in the traditional supply and demand framework. On the supply side the following need to be considered:

(1) Traditions and attitude affecting farming methods and practices. Can people be induced by economic incentive to change customs and practices?

(2) Available technology. Do farmers have access to combinations of improved practices or production techniques which are adapted for soil and climatic conditions?

(3) Diffusion of knowledge about improved technology. Farmers obviously need to know about improved production practices if they are to adopt them.

(4) Supplies of additional inputs, including land, labor, and capital. Most improved production methods, even better seeds, require additional capital inputs. Are they available, and if so, at what price?

(5) Tenure, credit, taxation, and marketing systems, with reference to how they influence production and marketing costs.

"On the demand side, the following merit attention:

(1) Population and income growth in nonagricultural sectors that cause demand for farm products to increase and to change in composition.

(2) Export markets for agricultural products. These may expand less than domestic markets, depending upon the product.

(3) Increases in subsistence demand resulting from farm population growth.

(4) Tenure, credit, taxation, and marketing systems with regard to how they affect prices received by farmers and the quantities of products that can be sold at these prices.

(5) Transportation, storage, and processing facilities that influence demand and prices of farm products at the farm level" (p. 70).

In another article, LeBlanc and Hrubovcak model the effect of interest rates on agricultural machinery investment and find that the level of investment is only slightly sensitive to interest rates; the rate of adjustment is sensitive to interest rates, but not so sensitive as to the ratio of machinery price to output price.

Huang presents a mixed structure-time series model of fresh meat prices that provides both a structural explanation of meat prices and an improved forecasting capability.

Gerald Schluter

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Productivity and Structure in U.S. Agriculture

By Clark Edwards*

Abstract

Changes in productivity are usually associated with technology. At the firm level, this is a natural way to think about productivity. However, in aggregate analysis, measures of productivity can change even when technology does not. The measures change when the proportions of farms in stable technological situations change. For example, more high yielding wheat on irrigated land in Arizona increases the national average wheat yield even though technology does not change either in Arizona or Kansas. Changes in the proportions of farms that are larger, incorporated, specialized, and operated by full-time farmers affect farm-sector productivity. The productivity of the farm sector is partly a function of structure.

Keywords

Technology, productivity, structure, aggregation, farm

Introduction

Productivity is a general term, frequently associated with ratios of output to input and sometimes with ratios among inputs (labor/capital) or outputs (crops/livestock). We usually think of changes in these productivity ratios as indicators of technical change. But, when the ratios use aggregate statistics (national summaries, for example), they can be affected by shifts within the aggregates, such as a shift in corn acreage from Iowa to Georgia. Hence, aggregate measures of productivity can change even when there is no change, from the farm manager's viewpoint, in technology.

For example: suppose a farmowner acquires control over a 40-acre field which had been in pasture and puts it in corn. The size of the farm is increased by 40 acres, and it may be in a higher sales class. If the added acreage is rented, the tenure class is changed. If the farm is incorporated in connection with the acquisition, the type of farm organization is changed. An accompanying change in management could result in a change in the age and chief occupation of the operator. The change in cropping results in a reclassification of the commodity specialization of the farm. If the decision is implemented outside the Corn Belt, say in the Southeast, then the aggregate statistics show a regional shift in the location of corn production. If the decision is implemented in the Southwest, the chances are that the additional 40 acres will be irrigated. This action will not be seen as a change in technology to the Southwestern farmer who irrigates as a matter of course, but it will appear as technical change in the aggregate statistics as more irrigated corn is produced relative to dryland corn. If the yield per acre on the additional land is above the national average, the national average yield increases and aggregate productivity will be said to increase. These changes resulting from a farm management decision are all seen in aggregate descriptions of agriculture as structural shifts. They are not seen by the farm manager as technological change, yet they are important in explaining changes in aggregate measures of productivity.

The aggregate statistics reflect changes in both technology and structure. The accompanying changes in the ratios of, say, machinery to land as more land is used with the same machinery, or of labor to machinery as more labor is used, are interpreted in the aggregate statistics as indicators of

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technological change, although the farmer may not have considered them so. In addition, some changes considered by the farmer to be technological might be a part of the decision to gain control over the additional land. New and larger planting and harvesting equipment might be acquired, fertilizing and cultivating practices might be changed, or a higher yielding crop variety might be adopted.

This single decision, considered as a whole by the farmer, is separated in economic analysis into three parts: changes in structure, changes in technology, and changes in productivity. Associating the change in productivity with a change in technology, assuming constant structure, can miss the most important aspect of change. This is not to say that structural change causes technical change or that technical change causes structural change. Which of the two is causal is not at issue here. What is at issue is that we have to learn to talk simultaneously about both as parts of a whole process rather than try to analyze them as separable processes.

The example suggests that we must consider technology and structure together as we try to explain productivity. Analytical models used in agricultural economics frequently assume that output is a function of technology by specifying yield equations in conjunction with acreage-harvested equations. The yield equations are fit to time-series data and frequently include time as an explanatory variable on the assumption that technology is adopted in such a way as to increase yields over time. The yield equations may also include price ratios on the assumption that a cost/price squeeze limits the use of inputs such as fertilizer and reduces the incentive to adopt output-increasing practices. The yield equations sometimes include acreage planted, on the assumption of diminishing returns to land. Such models explicitly (or, at least, through explicit interpretation of the trend coefficient) incorporate technological advance as a means of increasing farm output, but the structural changes that were part of the farm management decisions leading to the increase in productivity are omitted. The yield equations do not explicitly recognize the relation of structure to productivity. A specification which recognizes and incorporates structural change may improve the ability of economic models to explain and predict agricultural behavior.

Let us narrow the idea of productivity to include only crop yield per acre. Under this narrower definition, this study illustrates, using the national (and, occasionally, State) summary tables from the *1982 Census of Agriculture*, that productivity varies with structure. Little is said here about technology, although some indications of technology are available from these data, such as machinery investment per acre and fertilizer applied per acre. The hypothesis under consideration is that aggregate measures of productivity are affected by structural change. If yields are not significantly affected by structural changes, then the implication is to continue business as usual—that is, to assume that productivity change can be adequately explained by technological change without reference to structural change. However, the data suggest that there is a relationship between structure and productivity and that agricultural economists need to develop ways to use this relationship in their descriptions and analyses.

The tests of the hypothesis that follow are limited by the available data. A number of summary tables are published by the Census. Each gives a one-way tabulation of yield and other farm characteristics by a structural measure such as farm size or sales class. The source does not permit a two- or more-way cross-classification such as yield by farm size by sales class. Therefore, the results are based on a series of one-factor experiments where a single multifactor experiment would be more fitting. Consequently, the results are suggestive, not conclusive. Conclusive tests require more detailed tabulations of the cross-sectional data and of longitudinal data.

Corn Yield by Acres Harvested per Farm

The relation of aggregate corn production to corn acreage harvested per farm is shown in table 1.

Yield in bushels per acre is highly correlated with the acres harvested for corn per farm; higher yields per acre are consistently obtained from larger acreages (fig. 1). This relationship suggests that, as farmers continue to increase farm size and reduce the number of farms, the output of U.S. agriculture is likely to increase.

Table 1—Corn yield, by acres harvested per farm

Farm size	Farms	Harvested cropland per farm	Yield per acre	Share of output
	Number	*Acres*	*Bushels*	*Percent*
Total, all farms	715,171	97.68	107.49	100.00
1 to 14 acres	169,322	6.84	78.59	1.21
15 to 24 acres	75,385	18.80	86.64	1.63
25 to 49 acres	118,291	34.95	93.47	5.15
50 to 99 acres	131,659	69.44	99.38	12.10
100 to 249 acres	152,232	153.22	106.27	33.01
250 to 499 acres	50,896	332.73	113.12	25.51
500 to 999 acres	14,470	643.66	116.21	14.41
1,000 acres or more	2,916	1,519.68	118.04	6.97

Source: *1982 Census of Agriculture*, United States Summary, Table 41, Specified Crops by Acres Harvested.

However, conclusions about cause and effect cannot be drawn from the data in the Census tables because of the limitations of one-way tabulations and because the tables do not report additional explanatory factors. Two omitted factors deserve consideration. Because the operators of large farms may have more education and better management skills, they might have obtained higher yields from smaller farms if they chose to operate them. And, the operators of larger farms may control the best land, leaving the poorer land for use by smaller farmers.

The evidence from the corn enterprise suggests a positive correlation between farm size and yield. However, inasmuch as 80 percent of the grain is harvested from farms of 100 or more acres which

Figure 1

Corn Yield by Acres Harvested per Farm

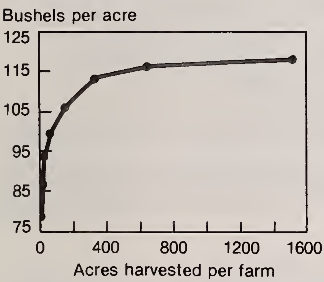


Figure 2

Wheat Yield by Acres Harvested Per Farm

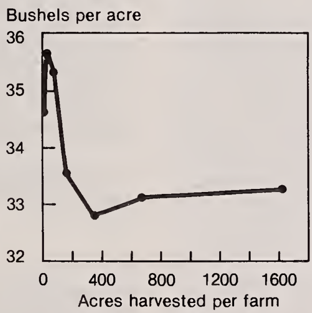


Figure 3

Soybean Yield by Acres Harvested per Farm

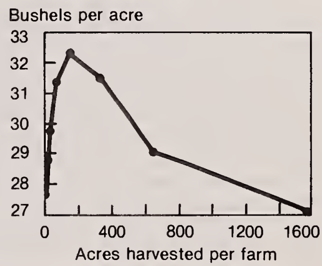


Figure 4

Wheat Yield by Value of Products Sold

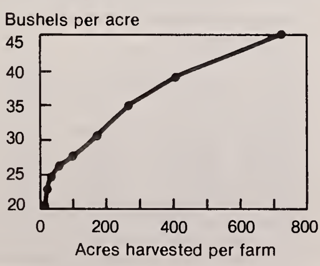
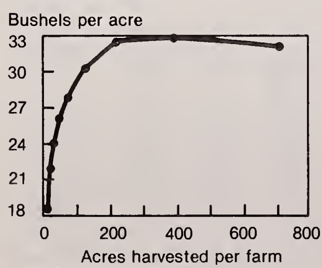


Figure 5

Soybean Yield by Value of Products Sold



have yields of about average or above, the potential effect of farm size on corn production, as indicated in the table, does not appear to be dramatic. That is, the hypothesis that productivity is associated with structure may be true, but may not be empirically important.

A similar, monotonically increasing pattern of yields with respect to number of acres harvested per farm appears for several other crops, including sunflower seed, cotton, rice, and alfalfa. However, a look at some other enterprises suggests that, while it is true that structure and productivity are functionally related, the relation may not be monotonically increasing.

Wheat Yield by Acres Harvested per Farm

The relation of aggregate wheat production to wheat acreage harvested per farm in shown in table 2.

Wheat yield in bushels per acre is bimodal, with the higher yields on the larger as well as the smaller farms, and with lower yields on farms harvesting from 250 to 499 acres (fig. 2); 67 percent of the wheat is grown on fields of 250 or more acres. Throughout the range of these larger farms there is little apparent trend of yield with respect to size, and the average yield on the larger farms is below the average on the smaller farms. These data appear to conflict with the hypothesis; the larger fields, which produce most of the wheat, have lower yields than the smaller fields. A U-shaped curve also appears for sugar beets and tobacco.

Table 2—Wheat yield, by acres harvested per farm

Farm size	Farms	Harvested cropland per farm	Yield per acre	Share of output
	Number	*Acres*	*Bushels*	*Percent*
Total, all farms	446,075	158.96	33.47	100.00
1 to 14 acres	73,594	8.38	34.63	.90
15 to 24 acres	54,452	18.81	35.67	1.54
25 to 49 acres	77,877	34.65	35.67	4.06
50 to 99 acres	74,189	68.49	35.33	7.57
100 to 249 acres	85,276	155.35	33.54	18.72
250 to 499 acres	45,977	345.45	32.81	21.95
500 to 999 acres	25,076	667.43	33.12	23.36
1,000 acres or more	9,634	1,621.62	33.27	21.90

Source: *1982 Census of Agriculture*, United States Summary, Table 41, Specified Crops by Acres Harvested.

The U-shaped distribution for wheat is partly explained by regional location, which implies not only climate but type of wheat grown and type of technical practices which are appropriate. Wheat yields by State are highest in Arizona, California, Idaho, and Nevada, where most of the wheat is irrigated. They are lowest in Colorado, New Mexico, South Dakota, Texas, and Wyoming. Within Kansas, the State with the largest acreage seeded in wheat, wheat yields increased monotonically with acreage harvested—from 26 bushels on the smaller farms to 33 bushels on the larger ones, with a State average of 32 bushels. In Arizona, the State with the highest yield, all the wheat is irrigated; even the smaller farms have yields well above the national average. As in Kansas, Arizona yields increase monotonically with farm size.

Adjusting the aggregate summary for regional location, which controls for land quality, type of wheat, and farming practices appropriate to the region, lends support to the hypothesis that productivity increases with size of farm.

Soybean Yield by Acres Harvested per Farm

The relation of aggregate soybean production to soybean acreage harvested per farm is shown in table 3.

Soybean yields in bushels per acre are lower on the larger as well as the smaller farms and are higher on the farms harvesting 100 to 249 acres (fig. 3). Farms with 100 acres or more planted in soybeans account for 81 percent of the crop. As fields increase above 100 acres, yields appear to decrease. As inverted U-shaped curve also appears for barley, oats, and sorghum.

The inverted U-shaped distribution for soybeans is partly explained by regional location. Soybean yields are highest in Illinois, Iowa, Minnesota, Nebraska, and Ohio. They are lowest in North Dakota, Oklahoma, and South Carolina. Within each State, yields tend to increase with farm size. For example, within Illinois, the State with the largest acreage planted in soybeans, yields increased as the number of acres harvested per farm increased from

under 14 acres to 999 acres. Yields went from 32 bushels on the smaller farms to 38 bushels on the larger ones, with a State average of 37 bushels. For the farms of 1,000 acres and over, which account for only a small percentage of total production and tend to be located in a different part of the State, yields dropped to 35 bushels. For Oklahoma, the State with the lowest soybean yields, the yields are higher for the larger farms, yet still well below the U.S. average yield.

Again, the aggregate data appear to conflict with the hypothesis. But, after the aggregate summaries are adjusted for regional location, there again is support for the hypothesis that productivity increases with size of farm.

Yield by Size of Farm

The number of acres harvested per farm is correlated with the size of the farm; the acreage harvested per farm tends to be larger on the larger farms. However, the two series are not perfectly correlated because there are small corn fields on some larger farms, and some smaller farms plant corn fence to fence. Table 48, Summary by Size of Farm, in the *1982 Census of Agriculture*, provides yield data by size of farm. Had table 48 been used instead of table 41 as the basis for the above discussion, the details of the discussion would have been different, but the general conclusion would have been the same.

Table 3—Soybean yield, by acres harvested per farm

Farm size	Farms	Harvested cropland per farm	Yield per acre	Share of output
	Number	*Acres*	*Bushels*	*Percent*
Total, all farms	511,229	126.82	30.69	100.00
1 to 14 acres	56,552	8.64	27.64	.68
15 to 24 acres	51,790	18.95	28.78	1.42
25 to 49 acres	97,209	35.24	29.75	5.12
50 to 99 acres	110,872	69.46	31.34	12.13
100 to 249 acres	129,171	153.23	32.34	32.16
250 to 499 acres	45,711	333.87	31.48	24.15
500 to 999 acres	15,345	648.08	29.05	14.52
1,000 acres or more	4,579	1,580.51	27.03	9.83

Source: *1982 Census of Agriculture*, United States Summary, Table 41, Specified Crops by Acres Harvested.

For example, corn and cotton have the same monotonically increasing relationship whether tabulated by acres harvested per farm or by size of farm. And, soybeans retain the U-shaped relation in both tabulations. But, wheat and barley become monotonically decreasing, and alfalfa shifts from monotonically increasing to an inverted U-shape.

However, once again, adjustments for region generally support the hypothesis that larger farms are more productive than smaller ones. This finding—coupled with additional information discussed in subsequent sections of this article—suggests that the U-shaped and inverted U-shaped yield relationships become monotonically increasing when additional subsorts are made with respect to various structural attributes.

The most straightforward test of the hypothesis using the national summary of yield by size of farm is mixed. However, after inquiry behind the national summary data available in the tables, the story becomes less mixed and more supportive of the hypothesis, but not spectacular. Other national summary tables are published which sort by various structural variables—one at a time—such as sales class, tenure, and type of farm organization. These tabulations allow one to examine both yield and size of farm as various structural measures change. These data provide additional and stronger evidence that productivity is associated with structure. Furthermore, the size of farm is also correlated with each structural variable, and yield is consistently found to be a monotonically increasing function of the acres harvested per farm for most of the major crops.

Yield by Value of Products Sold

The relation of aggregate corn production to the value of products sold per farm is shown in table 4.

The number of acres harvested per farm is highly correlated with the value of products sold per farm, so the results of examining productivity by sales class appear to be about the same as examining productivity by size of farm. At least this finding is so for corn (the production of which is dominated by the homogeneous Corn Belt region) and for the

Table 4—Corn yield and acres of corn harvested per farm, by value of products sold per farm

Sales class	Farms	Harvested cropland per farm	Yield per acre	Share of output
	Number	*Acres*	*Bushels*	*Percent*
All farms	715,171	97.68	107.49	100.00
Total, $10,000 or more	546,581	123.68	108.59	97.77
$500,000 or more	9,946	622.50	122.48	10.10
$250,000 to $499,999	30,152	355.50	118.93	16.98
100,000 to $249,000	125,438	189.97	112.10	35.58
$40,000 to $99,999	182,194	98.44	101.75	24.30
$20,000 to $39,999	110,907	54.99	93.12	7.56
$10,000 to $19,999	87,944	32.17	86.27	3.25
Total, less than $10,000	168,118	12.89	73.27	2.11
$5,000 to $9,999	67,056	18.86	79.05	1.33
$2,500 to $4,999	45,419	11.83	70.54	.50
Less than $2,500	55,643	6.57	57.25	.28
Abnormal farms	472	186.05	98.25	.11

Source: *1982 Census of Agriculture*, United States Summary, Table 49, Summary by Value of Agricultural Products Sold.

other crops for which the national summaries indicated a monotonically increasing relation of yield to acres harvested per farm.

In addition, the subsort by value of products sold lends further support to the hypothesis that productivity is a function of structure. It does so by changing the U-shaped and inverted U-shaped yield curves into monotonically increasing functions of acres harvested per farm. It places, for example, larger farms with relatively low yields and, therefore, low total sales in the same class as small farms with relatively low sales. The relation of productivity to value of sales per farm is monotonically increasing for all the major crops, such as corn, wheat, cotton, and soybeans. When farms are sorted by sales class, the relation of productivity to number of acres harvested is also monotonically increasing for all the major crops.

The relation of aggregate wheat production to value of agricultural products sold per farm is shown in table 5. The comparable table for soybeans is omitted, but note in figures 4 and 5 that, when farms are sorted by value of sales per farm, the relation between farm size and yield is monotonically increasing for both wheat and soybeans.

Farms with lower yields on larger acreages, leading to inverted U-shaped relations, apparently have lower total sales, just as the farms with higher yields on smaller acreages, leading to U-shaped relations, have higher total sales. Classifying farms by sales instead of acres appears to adjust for this (partly regional) variation in intensity of land use. The cross-classification of farms by size and by sales class which should make this point clear is not published by the Census. These data support the hypothesis that productivity is associated with structure.

Yield by Tenure

The relation of aggregate corn production to tenure is shown in table 6.

Yield of corn in bushels per acre is higher for tenant farmers and part owners than for full owners (fig. 6). The tendency for full owners to have lower yields than tenants and part owners held for most major crops including sorghum, soybeans, wheat, and tobacco. An exception was for cotton, where the national summary showed that tenants had lower yields than full or part owners. Tenancy is more prevalent on cotton farms in Texas than in Georgia, the tenant farms are larger, and the cotton yields are lower. However, full owners in Texas operated smaller farms and obtained higher cotton yields than the other tenancy classes. According to the national summaries for most crops, most production is on farms operated by part owners who tend to have not only higher yields but also larger farms. These data suggest that, as farmers change from full owners to part owners and tenants, productivity increases. Farm size also increases, so productivity again appears to be an increasing function of farm size.

Table 5—Wheat yield acres of wheat harvested per farm, by value of products sold per farm

Sales class	Farms	Harvested cropland per farm	Yield per acre	Share of output
	Number	*Acres*	*Bushels*	*Percent*
All farms	446,075	158.96	33.47	100.00
Total, $10,000 or more	367,277	186.45	33.80	97.52
$500,000 or more	8,825	725.42	45.18	12.19
$250,000 to $499,999	21,929	410.17	39.01	14.79
100,000 to $249,000	77,748	266.25	34.98	30.51
$40,000 to $99,999	116,667	173.11	30.60	26.04
$20,000 to $39,999	79,814	104.30	27.70	9.72
$10,000 to $19,999	62,294	61.98	26.32	4.28
Total, less than $10,000	78,466	30.41	23.86	2.40
$5,000 to $9,999	40,687	38.79	24.71	1.64
$2,500 to $4,999	21,273	25.80	22.98	.53
Less than $2,500	16,506	15.68	20.57	.22
Abnormal farms	332	137.12	42.37	.08

Source: *1982 Census of Agriculture*, United States Summary, Table 49, Summary by Value of Agricultural Products Sold.

The summary by tenure of operator includes data for farms in two sales classes: above and below $10,000 per year. Farms in the lower sales class consistently had smaller farms and lower yields.

Yield by Type of Organization

The relation of productivity to type of farm organization is shown in table 7.

Yield in bushels per acre is a function of the type of organization; the largest farms with the highest yield are large, nonfamily corporations, and the smallest farms with low yield are individual or family farms (fig. 7). There are very few farms in the

Table 6—Corn yield and acres of corn harvested per farm, by tenure

Tenure class	Farms	Harvested cropland per farm	Yield per acre	Share of output
	Number	*Acres*	*Bushels*	*Percent*
All farms:				
Total	714,699	97.62	107.50	100.00
Full owner	309,599	55.22	102.29	23.31
Part owner	298,769	139.64	108.84	60.55
Tenant	106,331	103.02	110.51	16.14
Farms with sales of $10,000 or more:				
Total	546,581	123.68	108.59	97.88
Full owner	190,768	82.29	104.73	21.92
Part owner	265,291	155.50	109.31	60.13
Tenant	90,522	117.68	111.51	15.84
Farms with sales of less than $10,000:				
Total	168,118	12.89	73.27	2.12
Full owner	118,831	11.76	74.83	1.39
Part owner	33,478	14.00	67.40	.42
Tenant	15,809	19.07	75.16	.30

Source: *1982 Census of Agriculture*, United States Summary, Table 44, Summary by Tenure of Operator.

highest yielding group; large, nonfamily corporations produce only 0.14 percent of total corn production. Individual or family farms produce about 74 percent of the total.

These data suggest that farmers who incorporate tend to have higher productivity. For example, 90 percent of corporate farms are small family-held organizations. These farms have corn yields 11.6 percent above the yields of family and individual farms. If the family and individual farms were, through structural change, to acquire the characteristics of, and to have the same yields as, the smaller corporate family farms, total corn production from all farms would increase 8.6 percent.

Larger corporate farms have higher yields than other types of organizations for wheat and cotton as well as for corn. For rice and tobacco, the smaller family-held corporations have higher yields than other types. However, for all major crops, corporate farms tend to show consistently higher yields than do individual or family farms, partnership farms, and institutional farms. The type of farm organiza-

Figure 6

Corn Yield by Tenure

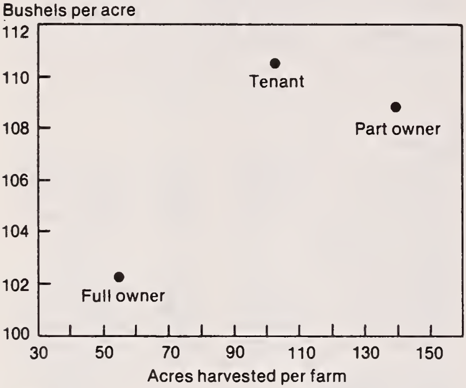


Figure 7

Corn Yield by Type of Organization

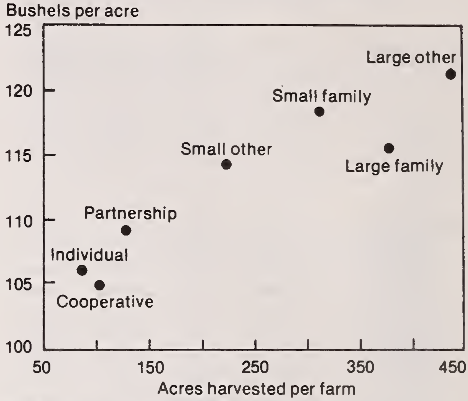
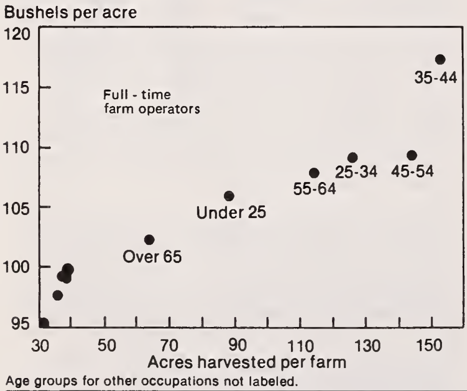


Figure 8

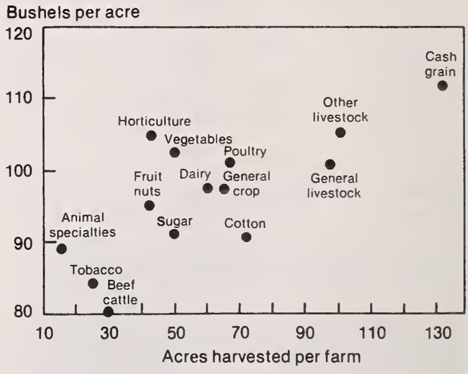
Corn Yield by Age and Occupation



Age groups for other occupations not labeled.

Figure 9

Corn Yield by Industrial Classification



tion that has the higher yields also tends to have the larger farms, so when farms are sorted by type of organization, productivity again appears, for all the major crops, as a monotonically increasing function of acres harvested per farm.

Yield by Age and Principal Occupation

The relation of productivity to the age and the principal occupation of farm operators is shown in table 8. Yield in bushels per acre is highest for full-time operators of 35 to 44 years of age, lower for those slightly older or younger, and lowest for the oldest and the youngest operators. Hence, a graph of yield by age has an inverted U-shaped. However, operators aged 35 to 44 years operate larger farms with higher yields; the oldest and the youngest farmers operate smaller farms with lower yields. So the yields are a monotonically increasing function of farm size (fig. 8). Most major crops display an in-

Table 7—Corn yield and acres of corn harvested per farm, by type of organization

Type of organization	Farms	Harvested cropland per farm	Yield per acre	Share of output
	Number	*Acres*	*Bushels*	*Percent*
Total, all farms	714,699	97.62	107.50	100.00
Individual or family	604,727	86.56	106.00	73.98
Partnership	88,761	128.53	109.09	16.59
Total corporation	18,659	308.37	118.11	9.06
Family held, total	17,241	313.00	118.25	8.51
More than 10 holders	480	376.83	115.53	.28
10 or fewer holders	16,761	311.18	118.34	8.23
Not family, total	1,418	251.99	116.03	.55
More than 10 holders	197	435.93	121.25	.14
10 or fewer holders	1,221	222.31	114.38	.41
Cooperative, estate or trust, institutional, and so forth	2,552	103.42	104.89	.37

Source: *1982 Census of Agriculture*, United States Summary, Table 45, Summary by Type of Organization.

Table 8—Corn yield and acres of corn harvested per farm, by operator's age and principal occupation

Age and occupation of operator	Farms	Harvested cropland per farm	Yield per acre	Share of output
	Number	*Acres*	*Bushels*	*Percent*
Total, all farms	714,699	97.62	107.50	100.00
Farming	519,798	120.36	108.51	90.52
Under 25 years	20,373	88.15	105.98	2.54
25 to 34 years	79,975	125.94	109.21	14.67
35 to 44 years	90,816	152.56	117.39	20.35
45 to 54 years	112,325	143.94	109.40	23.58
55 to 64 years	135,918	114.38	107.99	22.38
65 years and over	80,391	63.79	102.38	7.00
Other occupations	194,901	36.97	98.66	9.48
Under 25 years	5,485	37.22	99.23	.27
25 to 34 years	29,756	38.81	99.86	1.54
35 to 44 years	49,373	37.48	99.28	2.45
45 to 54 years	49,788	38.78	99.13	2.55
55 to 64 years	39,787	35.93	97.71	1.86
65 years and over	20,712	30.67	95.24	.81

Source: *1982 Census of Agriculture*, United States Summary, Table 46, Summary of Age and Principal Occupation.

verted U-shaped pattern of yields with respect to age and a monotonic yield-size relation. Exceptions are that older operators maintain relatively high yields for cotton and rice.

These data suggest that as full-time farmers in their midthirties to midforties acquire control of farms operated by older or younger persons, farm size and yield per acre both increase.

Operators who report that farming is not their principal occupation tend to report lower yields than full time farmers (table 8).

Yield by Standard Industrial Classification of Farm

The relation of productivity to the industrial classification of the farm is shown in table 9.

Yield in bushels per acre is related to the industrial classification of farms. The largest farms with the highest yields are those specializing in cash grains (fig. 9). These farms produce two-thirds of the total corn output. Another fifth of corn output is produced on farms which specialize in livestock enterprises such as cattle or hog feedlots; the acreage harvested per farm and the yields per acre for these livestock farms are only slightly smaller than for cash grain farms. These data suggest that specialization is related to increasing productivity and larger farms.

Conclusions

Two general conclusions follow from this examination of the national summary tables for the *1982 Census of Agriculture.* The first is that measures of aggregate productivity are not affected by technology alone but also by structural change. Three concepts distinguished by analysts—productivity, structure, and technology—are perhaps different aspects of a single process and can no more be separated from one another than the forest from the clearing, or the hill from the valley.

The second conclusion is that the summary tables published by the Census are suggestive, but do not

Table 9—Corn yield and acres of corn harvested per farm, by industrial classification of farm

Industrial classification of farm	Farms	Harvested cropland per farm	Yield per acre	Share of output
	Number	*Acres*	*Bushels*	*Percent*
Total, all farms	714,699	97.62	107.50	100.00
Cash grains	336,877	131.85	111.76	66.19
Cotton	1,272	71.97	90.61	.11
Tobacco	36,061	25.03	84.24	1.01
Sugar, potatoes, and other	14,957	49.68	91.07	.90
Vegetables and melons	4,764	49.98	102.55	.33
Fruits and tree nuts	1,598	42.06	95.14	.09
Horticultural specialties	549	42.70	104.91	.03
General farms, primarily crop	21,490	65.12	97.53	1.82
Beef cattle, except feedlots	53,121	29.45	80.09	1.67
Other livestock	129,556	100.76	105.34	18.34
Dairy	94,907	60.11	97.48	7.41
Poultry and eggs	6,296	66.89	101.10	.57
Animal specialties	1,826	15.24	89.06	.03
General, primarily livestock	11,425	97.51	100.82	1.50

Source: *1982 Census of Agriculture*, United States Summary, Table 50, Summary by Standard Industrial Classification of Farm.

in themselves provide a sufficient data base with which to definitively test the hypothesis that the measures of aggregate productivity are related to structure.

The summary tables are one-way tabulations; they sort farms by size and again by sales class, but do not cross-classify by size by class. What is required is two-way or even three- or more-way cross tabulations. These can be obtained from available data for national surveys, but the number of farms in these samples do not permit very much cross tabulation. The sheer size of the data base already collected by the Census permits much greater cross tabulation. Special runs are needed that use Census data which provide analytically useful cross tabuluations, longitudinal tabulations, and multiple regressions without violating disclosure rules for maintaining the privacy of respondents. The straightforward way of doing this—publication of all the data in a three- or four-way cross tabulation—is not efficient because it involves too many numbers and too many disclosure problems. But, there are other ways. Let me mention three: user tapes containing a 1-percent sample of individual farm records, a research-friendly data base which can be accessed with standard statistical software packages such as SPSS or SAS at moderate marginal cost per query, or a covariance matrix suitable for correlation, regression, and factor analyses.

When farmers make managerial decisions affecting output per unit of input, a change in technology is usually involved. The technological change may involve a new variety of crop, new cropping practices such as minimum tillage, different machinery, and others. And, the change may also involve what is called structure. The size of farm may increase; and the farm may be reclassified into a higher sales class, a different tenure ownership status, and a different specialization. If the decision involves a change in ownership, then the characteristics of the operator, such as age and principal occupation, may change.

The data available from the summary tables of the *1982 Census of Agriculture* support the hypothesis that the productivity of the farm sector is related to structure. Some of the tables suggest that the relationship exists, but is empirically small; others suggest the relationship may be substantial.

Larger farms consistently tend to have higher yields. The persistence of this conclusion surprised me more than any other finding as I examined the Census tables. The finding supports the maxim that "bigger is better" and counters the maxim that "small is beautiful." Consequently, it can affect how we feel about the displacement of families living on small farms.

Comparison with similar data in other countries is interesting. A positive relation between yield and farm size has been noted in Ireland, but the yield-size relation was found to be spurious and was explained by education of the operator. In West Germany, where the education of the operator of smaller farms is probably as high as those of larger farms and where the average size of farm is smaller than in the United States, the data do not reveal a

clear yield-size trend. Detailed analyses of agricultural Census data cannot reveal whether the yield-size relation noted for the United States is spuriously related to education or land quality, because such information is not collected by the Census.

It is usual in agricultural economics research to seek to explain yields as a function of technological change, but structure is seldom included as an explanatory variable. The findings here suggest that yield per acre should be specified as a function not only of technical change but also of structural change, such as acres per farm, sales class, tenure, type of organization, kind of specialization, and regional location. If this specification were made, it might be shown that yield equations for agriculture are relatively stable and that equations for agriculture productivity can be forecasted, explained, and modeled more accurately.

In Earlier Issues

Two dynamic forces active in 1941-50 are likely to have a lasting effect on the relationship of aggregate food expenditure to income: the shift of population from rural to urban areas and the change in manner of living reflected in increased processing of food outside the home, either in public eating places or in processing plants. These forces appear to have increased the dynamic income elasticity of demand for food by raising the general level of food expenditures. Lacking sufficient basis as yet for ascertaining the contribution of these enduring forces to the lower static income elasticity of demand that is evident in the 1947 urban data compared with 1941, we cannot estimate their possible offsetting effect upon future dynamic income elasticity of demand for food.

Marguerite C. Burk
July 1951, Vol. 3, No. 3

The Effects of Interest Rates on Agricultural Machinery Investment

By Michael LeBlanc and James Hrubovcak*

Abstract

Changes in real interest rates may affect the rate of adjustment of machinery to optimal levels. This finding results from the development and application of a theoretically consistent analytical framework for examining agricultural investment in machinery. Results from duality theory on restricted variable profit functions are incorporated into a longrun dynamic optimization framework where input use is affected by external adjustment costs.

Keywords

Agricultural investment, adjustment costs, user cost of capital

Introduction

Interest in the relationship between the agricultural sector and the macroeconomy was first stimulated by the large increases in agricultural prices in 1973 identified as an important cause of general price inflation. The effects of the macroeconomy on agriculture have grown in importance as agriculture has become more "internationalized" and has received major shocks from abroad (*32*).[1] In addition, the most recent economic recession provides ample evidence of the importance of monetary factors and aggregate demand on secular income growth in agriculture.[2]

This analysis identifies and measures the effects of interest rates on agricultural machinery investment. The pivotal role of farm machinery in transforming U.S. agriculture is well known.[3] Less well known, however, is how the mix of monetary and fiscal policy affects agriculture through its effect on interest rates. Identifying the relationship between the interest rate and agricultural investment takes on added significance in light of prospects for a continued policy of tight money supply and high real interest rates.

We examine the effects of interest rates by placing the agricultural investment decision in a framework where the optimal levels of all variable and quasi-fixed inputs are determined simultaneously. Results from duality theory on restricted variable profit functions are incorporated into a dynamic optimization framework where input use is affected by external adjustment costs (*8, 22, 41*). Although many other approaches are possible (such as cash flow, standard neoclassical, and securities value), we use this approach because of its comparatively well-developed theoretical foundations. This "third generation" dynamic framework generates investment functions which can be approximated by a flexible accelerator structure.[4] The speed of adjustment of quasi-fixed factors to optimal levels is endogenous and, therefore, varies through time. Shortrun demand functions for variable inputs depend on input and output prices and the stocks of quasi-fixed factors and reflect the interdependence of input use.

*The authors are economists with the Battelle Pacific Northwest Laboratories and the Agriculture and Rural Economics Division, ERS, respectively.

[1]Italicized numbers in parentheses refer to items in the References at the end of this article.

[2]Real net cash income decreased from $36.6 billion in 1979 to $30.1 billion in 1983. Projections for 1984 suggest little change from 1983 (*37*).

[3]Agricultural demand for durable inputs has been studied by Griliches (*12*), Lamm (*21*), and Penson, Romain, and Hughes (*29*).

[4]Berndt, Morrison, and Watkins (*5*) categorize dynamic models as belonging to either the first generation (single-equation models using a Koyck partial adjustment framework (*17*)), second generation (allowing input interaction, but only a limited theoretical basis for the adjustment process), or third generation (explicitly incorporating dynamic optimization).

The attractiveness of the dynamic model used in this analysis is that it is consistent with the profit maximization hypothesis. Changes in the time discount or interest rate directly affect both the optimal level of capital stock and the rate of investment. The interest rate indirectly affects the use of variable inputs by altering the level of quasi-fixed inputs.

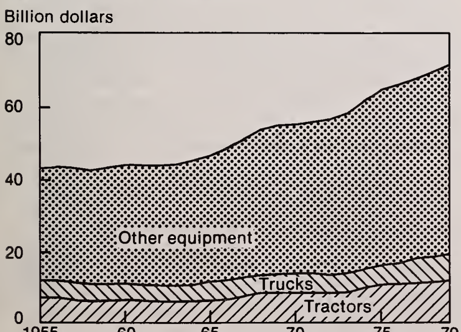
Input Use and Investment

During the last 25 years, there has been a large shift away from the use of labor and toward the use of machinery and chemicals in agriculture. The relative capital intensiveness of agriculture is evident when one compares the farm sector to the total economy. In 1979, for example, the agricultural sector used approximately twice as much physical capital per worker and three times as much physical capital per unit of production as did the economy as a whole (*7*).

After peaking in 1955, the real value of the total capital stock in agriculture (land, buildings, and machinery) has remained fairly constant, ranging from a high of $572 billion in 1955 to a low of $528 billion in 1978. Farm machinery, however, has increased dramatically since 1955 (fig. 1). The constant dollar quantity indices for tractors, trucks, and other farm machinery have increased from $8, $5, and $30 billion, respectively, in 1955 to $12, $7, and $53 billion, respectively, in 1979.

Figure 1

Agricultural Machinery



The shift to a more capital-intensive agriculture sector has also had a significant effect on the use of variable inputs. While the quantity of labor has declined by approximately 3.4 percent per year since 1955, there has been a dramatic increase in the use of manufactured inputs such as fertilizers and pesticides. The use of farm chemicals has increased by about 6.6 percent per year from 1955 to 1979.

Much of this shift away from labor and toward capital and chemicals is attributable to changes in relative input and output prices. During the fifties and sixties, farmers were able to reduce costs by expanding farm size and adopting farm machinery with lower cost per unit of output rather than using higher cost labor.

Nonfarm demand for farm labor also increased farm wage rates relative to other input prices. Nominal farm labor prices increased by approximately 4 percent per year from 1955 to 1970, while machinery prices increased by only 2.9 percent per year. The nominal price of agricultural chemicals actually declined from 1955 to 1972.

The ratio of chemical to output price fell dramatically from 1955 to 1973, whereas the ratios of both labor prices and machinery prices to output price rose slightly from 1955 to 1971 (fig. 2). The decrease in the ratio of chemical to output price increased demand for agricultural chemicals and increased the demand for complementary inputs. The increased demand for chemicals also decreased the demand for inputs (such as labor) which are substitutes for chemicals.

Stable output prices, in combination with Federal commodity programs which established minimum prices for many commodities, created an environment where farmers were encouraged to commit resources for a longer period by purchasing capital inputs.[5] The increased demand and the resulting increase in output prices resulting from exports during the seventies also stimulated the demand for capital inputs.

[5]Just points out that the uncertainty associated with changes which may take place in Government programs may affect investment decisions and lead to allocative inefficiencies (*16*). However, it can be argued that the establishment of many Government programs has led to more overall price stability in the sector.

Figure 2

Input/Output Price Ratio

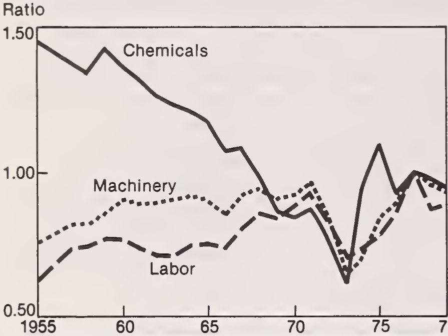
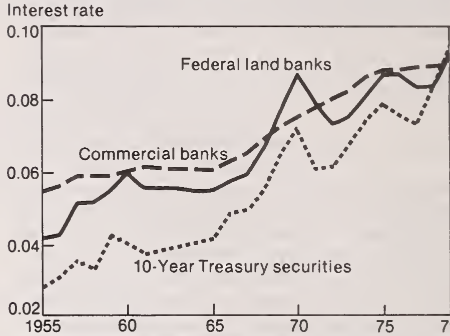


Figure 3

Nominal Interest Rates



The increased demand for farm capital has stimulated the demand for credit. Total real farm debt (1972 dollars), excluding farm households and Commodity Credit Corporation loans, increased from $21 billion in 1955 to $72 billion in 1979 (*37*). The interest rates that agricultural borrowers pay are closely related to interest rates in the general economy because loanable funds are obtained from the same sources (fig. 3). The Farm Credit System (FCS), comprised of Federal Land Banks (FLB's), Production Credit Associations (PCA's), and Federal Intermediate Credit Banks (FICB's), held $37 billion of nominal farm debt in 1979. FCS obtains loanable funds through the sale of securities in U.S. financial markets. Like any other banking organization, FCS typically boosts interest rates in the presence of tight monetary policies or increases in the nonfarm demand for funds. However, because FCS banks use average cost pricing (rates based on the average interest rate on all their outstanding bonds) rather than the more typical marginal cost pricing, interest rates on new loans tend to lag behind those of other lenders when interest rates rise.

Theoretical Model

During the sixties and early seventies, economists attempted to derive aggregate dynamic relationships from rational optimizing behavior.[6] In these analyses, the neoclassical view of frictionless market response was replaced by one where information is costly and irreversibilities exist. This framework was used to examine search behavior (*1*, *33*), transaction costs (*3*, *31*), and the formation of expectations (*6*, *24*). Although Barro (*3*) and Rothschild (*31*) examined adjustment behavior, their focus only on transaction costs led to results where firms adjust fully once a threshold is exceeded. Such an adjustment process, applied without other considerations, contradicted most empirical observations which suggest a gradual adjustment process.

Because the accelerator model has proved a valuable econometric tool, economists have sought a theoretical framework for the partial adjustment or accelerator model since Nerlove's early applied work (*25*, *27*). Many economists recognized this gap in economic theory where an elaborate theoretical structure, which existed for determining the level of an input, was combined with an *ad hoc* theory of adjustment. Eisner and Strotz developed a more

[6]Examples of these early attempts include the work of Eisner and Strotz (*8*) on the determinants of business investment completed under the auspices of the Commission on Money and Credit and a compendium of articles published in *Microeconomic Foundations of Employment and Inflation Theory* (*30*).

rigorous theory of adjustment by casting the firm in a dynamic optimization framework (*18*). The present value or net worth maximized by the firm depends on the optimal level of inputs selected by the firm and on the adjustment of the current capital stock to the optimal level.

More recently, Lucas (*22*), Gould (*11*), and Treadway (*36*) have extended the work of Eisner and Strotz. Although the models differ in their complexity, all have the same underlying structure postulated by Eisner and Strotz. Each specifies an objective function incorporating factor adjustment costs and a production function. The firm is assumed to maximize net worth over a given time period. Adjustment costs are interpreted either as foregone profits due to shortrun rising supply prices in the capital-supplying industry or as increasing costs associated with integrating new equipment into production (reorganizing production and training workers). These costs vary with the speed of capital adjustments. The models also assume that the values of the expected input and output prices do not change. This static or stationary expectations assumption is required if the dynamic optimization problem is to be well defined (*28*).[7] Because expectations are static, the firm adjusts to a fixed target considered to be the longrun equilibrium of neoclassical theory. Given these assumptions, a firm maximizing its present value changes capital stock in a manner similar to that suggested by the accelerator model.

Following Berndt, Fuss, and Waverman (*4*) and Berndt, Morrison, and Watkins (*5*), we can derive the optimal adjustment paths for the quasi-fixed inputs by incorporating a shortrun restricted profit function into a longrun dynamic optimization framework. The assumptions of competitive input and output markets are maintained. In addition, the model assumes that these competitive real prices are known with certainty and remain stationary over time.[8]

In the usual Marshallian framework, the relative fixity of inputs slows the adjustment to a new equilibrium position. Immediate adjustment is prevented because certain inputs cannot be changed until a given period of time has elapsed after the original decision to alter the inputs is made. If uncertainty is excluded, then the reason for slower rather than faster adjustment is that it costs the firm more to adjust production more rapidly. Following Eisner and Strotz, production factors are characterized as being more or less fixed as a function of the cost of varying the input sooner rather than later (*8*). We assumed that quasi-fixed inputs can be varied at a cost $C(\dot{K})$ where $\dot{K}$ equals dK/dt. That is:

$$\dot{K} = I - \delta K \tag{1}$$

where I is the gross addition to the stock of the quasi-fixed factor and δ is the rate of exponential depreciation. The normalized cost of adjustment is defined as:

$$C(\dot{K}) = qI + qD(\dot{K}) \tag{2}$$

where q is the purchase price of the asset divided by output price, $D(\dot{K})$ is a twice-differentiable function, and $D''(\dot{K}) > 0$. Adjustment costs at the initial time $t = 0$ are:

$$C(0) = q\delta K \tag{3}$$

This formulation assures constant marginal costs of replacement with increasing marginal costs of net change. Costs are expressed in units of the asset price of the quasi-fixed factors.

Net receipts, R(t), can, therefore, be written as:

$$R(t) = P[G(W,K) - C(\dot{K})] \tag{4}$$

where P is the unit price of output, G(W,K) is the Unit-Output-Price (UOP) restricted profit function, W is a vector of normalized (output price) input prices, and K is a quasi-fixed capital input.[9] If the

[7]This assumption could probably be relaxed if an alternative approach to the formation of expectations were allowed. For a comparison of a subjective Bayesian concept of rational expectations, see Swamy, Barth, and Tinsley (*34*).

[8]Nerlove (*28*) discusses how expectations can be incorporated into an adjustment cost model; however, his approach is empirically intractable.

[9]The restricted profit function represents the locus of shortrun maximized profit of a firm as a function of output price, input prices, and quantities of fixed factors (*19, 20*). The UOP profit function, therefore, is nonincreasing and convex in W (normalized input prices) and nondecreasing in P and K (*40*). The quasi-fixed input, K, may be vector-valued and represent more than one quasi-fixed input.

firm requires a rate of return, r, a weighted average of the rate of return to equity and the cost of external financing, then the present value of net receipts at time t = 0 is:

$$V(0) = \int_0^\infty e^{-rt} R(t)dt \tag{5}$$

The firm's longrun dynamic problem is to choose time paths for variable inputs, X(t), and the quasi-fixed input, K(t) to maximize V(0) given K(O) and X(t); K(t) > 0. Because G assumes shortrun optimizing behavior conditional on P, W, and K, the optimization problem facing the firm is to find, among all the possible G(W, P) combinations, the time paths of X(t) and K(t) that maximize the present value of net receipts.

One can obtain a solution to (5) by using either the Euler equation or Pontryagin's maximum principle. If static price expectations are assumed and profits and adjustment costs are normalized on output price, then the Hamiltonian necessary for applying the maximum principle is:

$$H(X,K,\dot{K},y,t) = e^{-rt}[G(W,K(t)) - C(\dot{K}(t))] + y\dot{K}(t) \tag{6}$$

where y is a costate variable, the dynamic equivalent of a Lagrangian multiplier of static optimization problems. Costate variables generally vary through time and are assumed to be nonzero continuous functions of time (*14*). Necessary conditions for the maximization of H require:

$$G'(W,K) - u - rC'(\dot{K}) + C''(\dot{K})\ddot{K} = 0 \tag{7}$$

where u is the normalized user cost of capital.

These necessary conditions are assumed sufficient to obtain a maximum. That is, the marginal profit associated with the quasi-fixed input equals its marginal cost of adjustment. Equation (7) has a stationary solution K*(P,W,r) which is obtained by setting $\dot{K} = \ddot{K} = 0$:

$$G'(X^*(K^*), K^*) - u - rC'(0) = 0 \tag{8}$$

The variable K* is the steady-state or longrun profit-maximizing demand for the quasi-fixed factor obtained by solving equation (8).

These results are linked to the partial adjustment or flexible accelerator literature because the shortrun demand for the quasi-fixed factor can be generated from equations (7) and (8) as an approximate solution in the neighborhood of K*(t) (*22*). The approximate solution is the linear differential system:

$$\dot{K} = B(K^*(t) - K(t)) \tag{9}$$

For a single capital input, the B matrix reduces to:

$$B = -0.5\,(r - [r^2 - 4H''(K^*)/C''(0)]^{0.5}) \tag{10}$$

Unlike most applications of the partial adjustment model, this derivation allows the adjustment coefficient, B, to depend on economic forces: the discount rate, the cost of adjustment, the production relationship embodied in the profit function, and the profit-maximizing behavior of the firm.[10] For example, an increase in the discount rate resulting from an increase in the rate of return to equity or an increase in the cost of external financing decreases the rate of adjustment and delays the addition of new capital stock. This result is observable if equation (10) is differentiated with respect to the discount rate:

$$\partial B/\partial r = -0.5(1 - r/[r^2 - 4H''(K^*)/C''(0)]^{0.5}) \tag{11}$$

Because $H''(K^*) < 0$ is required for the uniqueness of K* (*4*), $C''(0) > 0$ is true by assumption, and $0 < B < 1$ is required for stability of the adjustment process, the derivative $\partial B/\partial r < 0$. It is also apparent from equation (10) that as $C''(0)$ tends toward infinity, the adjustment coefficient tends toward zero (no adjustment) and, as $C''(0)$ tends toward zero, the adjustment coefficient tends toward 1 (complete, instantaneous adjustment).

The rate of adjustment of the ith capital good will generally depend on the difference between desired and actual stock for all capital goods. Therefore, the simplest form of the accelerator, equation (9), does not generalize easily. Lucas shows, however, that a

[10] See Nerlove (*26*) for a review of partial adjustment models and their application to agricultural problems.

sufficient condition for B to be a diagonal matrix is that the stock of the ith capital good demanded is independent of the prices and stocks of other capital goods (*22*). This is a strong assumption, but is necessary if one is to extend this theoretical framework to multiple capital inputs while maintaining a structure that can be estimated as a closed functional form.

The Empirical Model

Before the theoretical framework can be estimated, the adjustment equation must first be expressed as a difference equation, and functional forms for the profit and cost of adjustment functions must be selected. One can respecify the accelerator equation in a discrete form by first assuming that shortrun production is conditional on capital stocks at the beginning of the period. Therefore, capital stock adjustments during the period do not affect production until the following period. Second, the adjustment relationship specified in equation (9) can be replaced by:

$$K(t) - K(t\text{-}1) = B(K^*(t) - K(t\text{-}1)) \tag{12}$$

Quadratic approximations are used for both the profit function and adjustment cost function. We use a quadratic UOP profit function because its structure facilitates estimating the model without placing *a prioi* restrictions on the elasticities of substitution (*9*). The quadratic structure generates linear input demand functions and simple expressions for demand and substitution elasticities. Furthermore, the optimal paths for capital are globally rather than locally valid because the underlying differential equations are linear (*35*). The UOP profit function with Hicks' neutral technological change is specified as a quadratic function of normalized variable input prices and the level of capital available at the beginning of the current period is:

$$\pi = b + aT + \sum_{i=1}^{n} b_i W_i + b_k K + 0.5\left(\sum_{i=1}^{n} b_{ii} W_i^2 + b_{kk} K^2\right) + 0.5 \sum_{i=1}^{n} \sum_{j \neq i}^{n} b_{ij} W_i W_j + \sum_{i=1}^{n} b_{ik} W_i K \tag{13}$$

where b is the intercept, a is the parameter associated with the technological shift variable (T), b_i is associated with the normalized price of the ith variable input, b_k is associated with the capital stock, b_{ij} is associated with the product of the normalized prices of the ith and jth variable inputs, and b_{ik} is associated with the cross-product effects of the normalized price of the ith variable input and the capital stock.

Although there is no reason to expect that a quadratic adjustment cost function is correct in all circumstances, Gould found it to be a good approximation (*11*). A quadratic approximation to the cost of adjustment is:

$$C(\dot{K}) = qI + q(0.5d\dot{K}^2) \tag{14}$$

where D(0) = 0.

All that remain for completion of the empirical model are deriving the optimal level of capital stock and describing the adjustment process where current levels of capital move toward optimal levels. It is hypothesized that adjustment costs are external to the shortrun maximization decision. One can derive the necessary conditions for optimal capital adjustment by applying equation (7). The resulting equation:

$$b_k + b_{kk}K + \sum_{i=1}^{n} b_{ik}W_i - u - rqdK + d\dot{K} + qd\ddot{K} = 0 \tag{15}$$

is a second-order differential equation where $u = q(r + \delta)$ is the normalized user cost associated with the quasi-fixed factor. One can obtain the steady state solution by setting $\dot{K} = \ddot{K} = 0$:

$$K^* = -(b_k + \sum_{i=1}^{n} b_{ik}W_i - u)/b_{kk} \tag{16}$$

where K* is the optimal level of the capital stock.

The adjustment equation is therefore:

$$B = -0.5(r - [r^2 - 4b_{kk}/qd]^{0.5}) \tag{17}$$

Equations (16) and (17) are substituted into equation (12) to form:

$$K(t) - K(t-1) = -0.5(r - [r^2 - 4b_{kk}/qd]^{0.5})$$

$$(-(b_k + \sum_{i=1}^{n} b_{ik}W_i - u)/b_{kk} - K(t-1)) \quad (18)$$

Data

The analysis uses aggregate time series data for 1955 through 1979. A detailed description of the data is available in Ball (*2*). The data were aggregated by use of a discrete Tornquist approximation of a Divisia index. Ball computed Tornquist price indices first and then computed implicit quantity indices by dividing value (revenue or expenditures) by the Tornquist price index.

Ball formulated labor data to account for differences in the productivity of different types of workers and changes in quality due to education. For capital, the separation of price and quantity components of outlays is based on the correspondence between the value of an asset and the discounted value of its services (*13, 15*). The service price depends on the asset price, the rate of return, and the rate of replacement. The effect of income taxes on the service price of capital is not considered because of the difficulty of deriving a marginal tax rate for agriculture where a significant proportion of firms are either sole proprietorships (76 percent) or partnerships (13 percent) (*38*).[11] We separated outlays on capital into price and quantity components by combining the rate of return with the other components of the service price. The discount rate is assumed to be a weighted average of the longrun real interest rate (external financing) and the longrun real return to equity (internal financing). Weights were computed from 1969 and 1979 Farm Finance Survey data (*38, 39*). Interest rates for external financing were computed from rates charged by Federal Land Banks on new farm loans. The longrun rate of return to equity is based on Melichar (*23*) and Gertel (*10*).

Analysis

We estimated a flexible accelerator model of the form given by equation (18) with an appended classical error term for 1955 through 1978. Because the accelerator model is nonlinear in its parameters, we used a nonlinear maximum likelihood estimator.

[11]Shares are based on total operator farm assets.

Regressors include the ratio of input to output price for four classes of variable inputs (labor, chemicals, intermediate inputs, and energy), real discount rate, user cost of capital, and normalized price of machinery. The table shows the estimated value for each parameter and its associated asymptotic standard error and t-statistic. The R^2 statistic is 0.57. The estimated parameters generate a plausible model structure. Increases in the user cost of capital decrease investment. Increases in the normalized prices or labor, chemicals, and energy increase investment. Increases in the normalized price of intermediate inputs decrease investment. The model is dynamically stable in the sense that the estimated magnitude of the adjustment coefficient lies between zero and unity.

A plot reveals much greater variability in the observed data than the predicted data (fig. 4). The model predicts better in the latter half of the sample data and accurately captures the large increase in investment in 1973. The model predicts the first half of the sample less accurately than the second, although it generally predicts changes in the direction of investment.

Changes in interest rates affect investment in two ways. First, changes in the interest rate work through the user cost of capital to affect the optimal level of capital stock. Second, interest rates also affect the rate of adjustment of machinery to optimal levels.

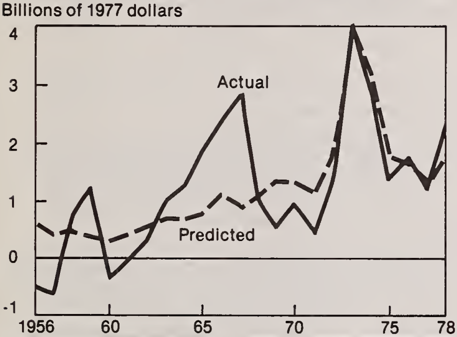
Estimated parameters and associated statistics

Coefficient	Value	Asymptotic standard error	Asymptotic t-statistic
b_k	80,299.40	4,227.87	19.0
b_{lk}	28,166.70	1,178.45	23.9
b_{ck}	51,827.20	3,661.43	14.2
b_{fk}	−48,061.40	−9,928.38	4.8
b_{ek}	65,391.10	5,602.68	11.7
b_{kk}	−.96	−.27	3.6
d	642.04	184.61	3.5

Note: Coefficient symbols are defined as follows: b_k is the intercept term for the optimal level of capital, b_{ik} is the coefficient associated with the ith normalized input price, l is labor, c is chemicals, f is intermediate materials, e is energy, k is machinery, d is the adjustment cost coefficient, and b_{kk} is the denominator of the optimal stock equation (18).

Figure 4

Predicted and Observed Net Investment



Recall from equation (16) that the optimal level of machinery is a function of the ratio of variable input to output prices and the user cost of capital. In its most detailed form, equation (16) is written:

$$K^* = -(b_k + \sum_{i=1}^{n} b_{ik}(\hat{W}_i/P) - (\hat{q}/P)(r + \delta))/b_{kk} \qquad (19)$$

where b_k, b_{ik}, and b_{kk} are parameters, $\hat{W}_i$ is the price of the ith variable input, P is the price of aggregate output, $\hat{q}$ is the purchase price of farm equipment, r is the real discount rate, and δ is the rate of economic depreciation. The effects of the interest rate on the optimal capital stock is given by the derivative $\partial K^*/\partial\eta = (\hat{q}/P)r'(\eta)/b_{kk}$ where $r'(\eta)$ is the rate of change of the discount rate with respect to the interest rate and η is the interest rate. We computed the derivative by substituting historical values for $\hat{q}$, P, and $\hat{W}_i$. The derivative varies from about 0.41 in 1955 to 0.52 in 1977. A 1-percentage point change, from 0.04 to 0.05 for example, reduces the optimal capital stock by about half a million dollars. Although the response of the optimal capital stock to changes in the interest rate is highly inelastic, less than – 0.01 in 1978, its sensitivity does increase through time.

Although interest rates do not significantly affect the optimal level of farm machinery, they do affect the rate of adjustment of machinery to optimal levels. The estimated adjustment rate from 1955 through 1971 staggered from 0.03 to 0.02 as real interest rates and the ratio of machinery prices to output prices increased (fig. 5).[12] Adjustment rates increased significantly between 1971 and 1974. In 1974, the estimated adjustment rate reached 0.045. This abrupt increase resulted from a sharp decrease in the real interest rate (discount rate) and a decrease in the normalized machinery price. The large increase in investment during the period has been attributed to the large increase in agricultural income.[13] Investment increased either because cash flow problems were reduced or farmers sought to avoid taxes by taking advantage of tax credits and accelerated depreciation tax provisions. Results from this analysis suggest a possible alternative explanation. Namely, the increase in investment can be attributed to an increase in the cost of foregone profits.

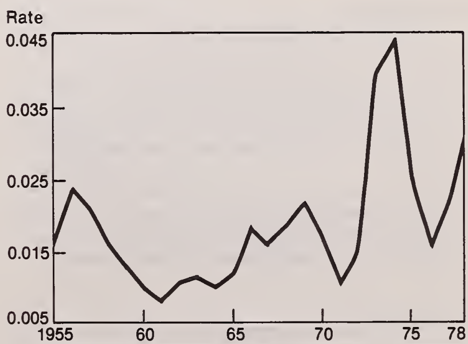
The results also indicate that the ratio of machinery price to output price is a relatively more important determinant of the adjustment rate than the real interest rate. The average machinery price elasticity of adjustment, $(\partial B/\partial q)(q/B)$, of – 1.03 is considerably

[12]The average interest elasticity of adjustment, $(\partial B/\partial r)(r/B)$, is – 0.014. The largest (absolute value) elasticity is in 1971 (– 0.03), and the smallest is in 1974 (– 0.01).

[13]Real net cash income jumped from \$32.6 billion in 1971 to \$38.3, \$49.9, and \$45.5 billion in 1972, 1973, and 1974 (*37*).

Figure 5

Rate of Adjustment



larger than the average interest elasticity, -0.014.[14] When interest rates are held constant and the ratio of machinery to output price is allowed to vary between 0.05 and 1.5, the adjustment rate ranges between 0.045 and 0.03. An increase in the price ratio indicates a higher machinery price relative to output price and acts as a brake on investment.

The composite effect of interest rates on net investment in farm equipment working through the adjustment coefficient and the user cost of capital is small. Although the weight of our results suggests little effect, a more cautious interpretation is that our results may not support an elastic investment response to changes in interest rates. Evidence regarding the effect of the interest rate on investment for other sectors is generally inconclusive. Eisner and Strotz, in their detailed review of investment studies, state: "The interest rate has occasionally been found to be negatively related to capital expenditures, but such findings are not general. Coefficients are frequently uncertain, or, more important, so small in relation to the variations of the interest rates which have been allowed to occur as to deny that variable much historical role in influencing the rate of investment" (*8*). Finally, the results suggest the primary determinant of net investment in this analysis is the ratio of input to output prices. Increases in the input/output price ratios for labor, chemicals, and energy stimulate the substitution of capital and motivate investment. This effect can result from either an increase in input prices or a decrease in output prices.

Conclusions

We have developed and applied a consistent theoretical framework for examining agricultural machinery investment. We incorporated results from duality theory on restricted profit functions into an optimal control framework and derived the necessary conditions for determining the optimal paths of quasi-fixed inputs using Pontryagin's maximum principle. Although strong assumptions are made about expectations, the final dynamic modeling system is a consistent theoretical framework.

Unlike other analyses, the adjustment coefficients developed here depend on economic variables (discount rate, output price, capital price, and adjustment cost) and are, therefore, not fixed through time.

One can draw three general conclusions from this analysis. First, changes in interest rates have a minor direct effect on the optimal level of agricultural machinery. Second, although the interest rate has little effect on the optimal level of machinery, it does affect investment by altering the rate of adjustment. Higher interest rates, *ceteris paribus*, delay investment because discounted profits are lower. Third, the ratio of machinery to output price also has a significant effect on the adjustment rate. Moreover, the adjustment rate is more sensitive to changes in this input/output price ratio than to the interest rate.

The dynamic theory offered in this analysis assumes static expectations. Future work needs to develop a theory where economic agents optimize their behavior in response to dynamic conditions and the formation of expectations are endogenously determined. A second limitation is that the theory uses an interequilibrium framework. That is, a firm moves from an initial to a final equilibrium position as a result of some change in external circumstances. Unfortunately, such a phenomenon can never be observed. Instead, the adjustment path must be derived from the observed data, thereby making the task of estimating meaningful parameters problematic. Finally, this analysis focuses on a subset of the total capital stock by making an important separability assumption. Preliminary work suggests, however, a more complete model specification may be limited econometrically by available data.

Although the effect of interest rates on investment is an important link between the macroeconomy and agriculture, it is only one of many that merit investigation. The effects of macroeconomic variables on investment in land and inventories, aggregate farm demand, and the formation of price expectations are also important. As contemporary events indicate, national and international economic phenomena have an increasingly important effect on the profitability and behavior of American agriculture.

[14]The machinery price elasticity data show about as much variation as the interest elasticity series.

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Monthly Demand Relationships of U.S Meat Commodities

by Kuo S. Huang*

Abstract

A set of price-dependent demand equations explains the interdependent nature of monthly demand relationships for 10 meat commodities. The analysis uses a model with a mixed structural-time series approach; the model's forecasting capability is significantly better than that of the traditional structural model used alone.

Keywords

Price-dependent demand structure, mixed structural-time series model

Introduction

The U.S. consumption expenditure for red meats and poultry accounts for approximately one-third of the consumer's food budget. Because there is limited knowledge about the interdependence of the demand relationships among meat commodities in the short run, an efficient forecasting model for monthly meat prices is difficult to obtain. Although previous studies have considered monthly demand behavior in the meat industry (*3, 7*),[1] few published studies have focused on the interdependent nature of these demands. This article analyzes this unexplored, yet important, facet of monthly demand and formulates a statistical model for improving the forecasting of meat prices. An inverse demand system approach is adopted for specifying the monthly demand relationships of meat commodities. In the statistical modeling, a mixed structural-time series model is applied; the results appear to have considerable potential to improve shortrun forecasting of meat prices.

Model Specification

According to the classical demand theory, the economic problem of a representative consumer is to choose commodities under a budget constraint so that the consumer's utility function is maximized. Let q denote an n-coordinate column vector of quantities, p an n-coordinate vector of their prices, $m = p'q$ the consumer's total expenditure, and U(q) the utility function. The primal function for consumer utility maximization is maximizing the following Lagrangian function:

$$\underset{q,k}{\text{Maximize}}\ L = U(q) - k\,(p'q - m) \tag{1}$$

The necessary conditions for an optimum are obtained as:

$$U_i'(q) = k\,p_i, \qquad i=1,2,\ldots,n \tag{2}$$

and:

$$p'q = m \tag{3}$$

in which $U_i'(q)$ is the marginal utililty of the ith commodity. By multiplying q_i in equation (2) and summing over n to satisfy the budget constraint of (3), the Lagrangian multiplier is:

$$k = \sum_{j=1}^{n} q_j\,U_j'(q)/m \tag{4}$$

Substituting equation (4) into (2) yields the Hotelling-Wold identity (*5, 11*):

$$p_i = m\,[U_i'(q) \,/ \sum_{j=1}^{n} q_j\,U_j'(q)] \tag{5}$$

$$i = 1,2,\ldots,n$$

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[1]Italicized numbers in parentheses refer to items in the References at the end of this article.

This equation represents an inverse demand system in which the variation of price is a certain function of quantities demanded and is proportional to a change in income. As indicated by Hicks (*4*), the Marshallian demands have two functions: one shows the amounts consumers will take at given prices, and the other shows the prices at which consumers will buy at given quantities. The latter function, "quantity into price," is essentially what the identity expresses.

The inverse demand system has considerable appeal as applied to the shortrun demand for meat commodities. For example, beef takes about 27 months from breeding until slaughter weight, and the change of market supplies tends to be rather inflexible in the short run. The aggregate quantity demanded for such a commodity becomes increasingly fixed as the time frame becomes shorter. Thus, if a monthly demand structure for meats is specified, assumptions that quantities and income are predetermined and that prices must be adjusted may be reasonable. Waugh rationalized that, in competitive markets, changes in prices are generally determined by changes in quantities marketed and changes in income, not the other way around (*10*). Most recently, Theil worked on a demand subsystem for beef, pork, chicken, and lamb by taking quantity changes as predetermined variables, on the justification that the role of meat prices is to insure that the market is indeed cleared (*9*). Thus, prices are endogenous in the demand-and-supply system.

When monthly demand relationships for U.S. meat commodities are specified, questions regarding the available data sources and the functional form of the demands are of immediate concern. The available monthly data for meat commodities are rather limited, and the defined prices and quantities do not always correspond closely. Monthly price observations, covering January 1964 to December 1979, for five beef products and four pork products are available from the U.S. Department of Labor, Bureau of Labor Statistics. The products include sirloin steak, round steak, chuck roast, round roast, ground beef, pork chops, canned ham, bacon, and sausage. Monthly price observations for broilers and the per capita quantities for meats over the same period are available from the Economic Research Service. The quantities include beef, veal, pork, lamb, broilers, turkeys, and other chicken. These quantities, measured in retail weight equivalents, are derived from the commercial carcass weight of various meat animals. The correspondence between the price and quantity variables, although not ideal as required by the conceptual demand relations, is about as close as can be achieved with the limited data available.

On the choice of functional form for the empirical fitting, the loglinear approximation of the Hotelling-Wold identity is used in this article largely for practical reasons. The estimated demand parameters represent demand flexibilities which are easily interpreted. The specification provides a convenient form for further elaboration in specifying the residual structure and in improving forecasting capability of the model.

The statistical model for the ith price equation in terms of n quantities demanded and an autoregressive process of residuals lagged up to k months follow:

$$\log(p_{it}/m_t) = \alpha_{io} + \sum_{j=1}^{n} \alpha_{ij} \log q_{jt} + \sum_{j=1}^{11} \gamma_{ij} d_{jt} + u_{it} \tag{6}$$

and:

$$u_{it} = \sum_{j=1}^{k} \beta_{ij} u_{i,t-j} + \epsilon_{it}, \qquad i = 1,2, \ldots n \tag{7}$$

where variables at time t are p_{it} (price of ith commodity), m_t (per capita income), q_{jt} (quantity demanded for jth commodity), and d_{jt}s (dummy variables assigned for sequential months from February to December to reflect the effects of monthly shifts); u_{it} and ϵ_{it} are respectively random disturbances in which ϵ_{it} is assumed to be normal and independently distributed, N (O, σ^2I).

In addition to the use of quantities as explanatory variables in equation (6), including monthly dummy variables in the equation reflects the possibility of seasonal variation in the demand for particular meat cuts, the possibility of seasonal difference in production costs, and the number of different graded meat animals being marketed. Shepherd and Futrell give some detailed explanations about the latter possibililty (*8*). For instance, there is a rather inflexible supply of potential hog processing and marketing services during the short run in terms of

plant facilities and labor supply. A dwindling seasonal supply of hogs causes sharply increased buying competition among packers and forces the packers to take a lower margin for their processing and wholesaling services. Consequently, the meat price in that season may not be as high as would be expected because of quantity change.

Furthermore, the residual specification of equation (7) reflects a suggestion by Muth that there is little empirical interest in assuming that the disturbance term in a structural model is completely unpredictable (*6*). It is desirable to assume that past of the disturbance may be predicted based on part observations. Because the expected values of the disturbance could be related to economic conditions prevailing in the past months, we may assume that the disturbance is not independent over time but follows an autoregressive process. Accordingly, the model has some practical advantages for improving forecasting capability. The structural component may provide forecasts for identifying the turning points of historical observations, whereas the time series component provides predictive information for the movements of random disturbance.

Estimation Procedures

The proposed statistical model on monthly demand relationships for meat commodities can be viewed as a mixed structural-time series model. The model not only provides a structural explanation of meat prices in equation (6), but also replicates the past behavior of residuals by specifying an autoregressive process in equation (7). To estimate the model, one needs a three-step estimation procedure because the disturbance terms in the autoregressive process are not observable. First some preliminary estimates of the structural parameters in equation (6) are obtained from ordinary least squares. Within the context of serial autocorrelated errors, these estimates are known to be unbiased but inefficient, and thus a further re-estimate is required. Second, the estimated residuals from the first step are used to fit the autoregressive process in equation (7). In this stage, the choice of lag order in the process can be determined by the significance of estimated coefficients in the equation. Given an appropriate order for the lags, one can obtain the autoregressive coefficients in a particular equation by solving the so-called Yule-Walker equations (*1*). Third, based on the estimated autoregressive structure in equation (7), the structural parameters are reestimated by the application of an Aitken estimation procedure suggested by Gallant and Goebel (*2*).

Estimation Results

Table 1 summarizes the estimatiion results. The values in each column express the price of a meat commodity as a function of seven meat quantities consumed, "other goods," a set of monthly dummy variables, and an autoregressive residual series. The "other goods" in the consumer budget is defined as per capita a nonfood expenditure measured in constant 1967 prices. Because each equation expresses price as a function of quantities in logarithmic form, the response coefficients can be called "flexibilities."

According to the estimation results, the direct-price flexibility between the price of sirloin steak and the quantity of beef is -0.342, which indicates that if consumers make a 1-percent decrease in quantity of beef purchased, the price of sirloin steak will increase about 0.3 percent. Similar interpretation is given to the direct-price flexibility of other items. The estimated direct-price flexibilities of monthly demand for various meat cuts are less than 1 in each case. They are round steak (-0.377), chuck roast (-0.508), round roast (-0.332), ground beef (-0.418), pork chops (-0.581), canned ham (-0.207), bacon (-0.845), sausage (-0.457), and broilers (-0.410). The prices of round steak, chuck roast, round roast, and ground beef are functions of all beef; the prices of pork chops, canned ham, bacon, and sausage are functions of all pork.

Special caution should be taken in interpreting cross-price flexibilities as the conventional view of substitution and complement between two goods. Hicks distinguished the substitution relationship in the inverse demand system as q-substitutes from that in the ordinary demand system as p-substitutes; he said that "X and Y are q-substitutes when a rise in the quantity of X diminishes the marginal valuation of Y (or the price at which a fixed quantity of Y would be purchased) when the quantities of all commodities other than X are fixed, saving the

Table 1—Estimated shortrun flexibilities for meat commodities

Independent variable	Price of–									
	Sirloin steak	Round steak	Chuck roast	Round roast	Ground beef	Pork chops	Canned ham	Bacon	Sausage	Broilers
Quantity:										
Beef	–0.342	–0.377	–0.508	–0.332	–0.418	0.101	0.115	0.375	0.100	0.100
	(.067)	(.072)	(.094)	(.067)	(.088)	(.082)	(.063)	(.115)	(.092)	(.133)
Veal	–.006	–.008	–.012	–.012	–.040	–.011	–.001	.008	.002	.008
	(.010)	(.011)	(.015)	(.011)	(.014)	(.014)	(.009)	(.018)	(.014)	(.022)
Pork	–.004	–.027	–.030	–.035	.073	–.581	–.207	–.845	–.457	–.363
	(.049)	(.052)	(.067)	(.048)	(.063)	(.059)	(.047)	(.084)	(.067)	(.094)
Lamb and mutton	–.004	.001	–.009	.001	–.001	–.015	–.007	–.010	–.010	–.002
	(.010)	(.011)	(.014)	(.010)	(.014)	(.014)	(.008)	(.018)	(.014)	(.020)
Broilers	.155	.143	.210	.140	.168	.286	.096	.247	.219	–.410
	(.064)	(.070)	(.091)	(.065)	(.087)	(.084)	(.056)	(.110)	(.087)	(.132)
Turkeys	–.006	.012	.003	.009	.014	.046	.011	.033	.009	.033
	(.017)	(.017)	(.023)	(.016)	(.022)	(.022)	(.015)	(.030)	(.023)	(.033)
Other chicken	.045	.064	.075	.062	.031	.060	–.021	.044	.005	.095
	(.022)	(.024)	(.031)	(.022)	(.030)	(.030)	(.019)	(.038)	(.030)	(.044)
Other goods	–.602	–.645	–.531	–.749	–.505	–1.188	–.614	–1.020	–.387	–.868
	(.088)	(.098)	(.125)	(.091)	(.118)	(.111)	(.091)	(.150)	(.122)	(.179)
Monthly dummy:										
Constant term	2.099	2.634	1.955	3.347	1.345	6.639	1.554	5.201	.177	3.166
February	–.020	–.013	–.005	–.013	–.012	–.004	–.005	–.008	–.014	–.030
March	–.012	–.003	.017	–.003	–.001	.026	.005	.047	.026	–.047
April	–.024	–.020	–.017	–.022	–.023	–.027	–.015	.011	.001	.020
May	–.006	–.009	–.009	–.014	–.012	–.073	–.043	–.042	–.037	.060
June	.032	.007	.007	.003	.002	–.064	–.065	–.064	–.043	.074
July	.044	.011	.021	.006	.004	–.039	–.082	–.076	–.048	.077
August	.041	.011	.026	.005	.007	–.024	–.065	–.024	–.016	.068
September	.048	.008	.026	.005	.006	–.007	–.051	.022	.015	.011
October	.022	–.006	.018	–.007	–.002	–.024	–.034	.026	.023	–.033
November	.012	–.024	.001	–.021	–.030	–.026	–.017	.028	.044	–.132
December	–.008	–.034	–.013	–.028	–.040	–.038	–.009	.020	.024	–.117
Residual:										
Lag 1 month	.467	.328	.346	.345	.286	.264	.618	.491	.471	.267
Lag 2 months	.115	.179	.131	.150	.168	.070	.060	–.066	.029	.129
Lag 3 months	.131	.247	.240	.262	.254	.274	.149	.237	.232	.342

Note: The figures in parentheses are the estimated standard errors. All income flexibilities are constrained to unitary values on the basis of equation (4).

quantity of money, which is adjusted so as to maintain indifference" (4).

To illustrate, considering a demand system with only two substitutable goods, we can present the system in elasticity matrix form in which the direct-price elasticities are negative and the cross-price elasticities are positive:

$$\begin{bmatrix} q_1 \\ q_2 \end{bmatrix} = \begin{bmatrix} -e_{11} & e_{12} \\ e_{21} & -e_{22} \end{bmatrix} \begin{bmatrix} p_1 \\ p_2 \end{bmatrix} \quad \text{for positive } e_{ij}, \; i,j = 1,2$$

where p_i and q_i are, respectively, nominal price and quantity for ith goods expressed in logarithms, and where e_{ij}'s are the absolute value of demand elasticities. One can derive the inverse demand system by inverting the elasticity matrix and obtaining:

$$\begin{bmatrix} p_1 \\ p_2 \end{bmatrix} = \begin{bmatrix} -e_{22}/D & -e_{12}/D \\ -e_{21}/D & -e_{11}/D \end{bmatrix} \begin{bmatrix} q_1 \\ q_2 \end{bmatrix}$$

where $D = e_{11} e_{22} - e_{12} e_{21}$. Because the direct-price flexibilities ($-e_{22}/D$ and $-e_{11}/D$) are negative for utility maximization, the value of D should be positive. Consequently, the cross-price flexibilities ($-e_{12}/D$ and $-e_{21}/D$) are negative for the case of substitutable goods. In other words, a marginal increase of the quantity of one good may have a substitution effect on the other goods, and the price of other goods should be lower to induce consumers to purchase the same quantity of the other goods.

The relationships of substitution and complement depend on the compensated cross-price flexibilities in which the level of consumer utility is fixed. Thus, in the absence of assuming a fixed utility level, the estimated cross-price flexibilities of table 1 may roughly reflect substitution of the negative sign and complement of the positive sign. For example, the figure in the last column for the price of broilers associated with the quantity of pork is -0.363 which implies that the two commodities are substitutable. A marginal 1-percent increase in the quantity of pork is associated with a -0.363-percent decrease in the price of broilers to induce consumers to purchase the same quantity of broilers. In the same column, the figure related to the quantity of other chicken is 0.095, which may be complementary to broilers. An increase in the quantity of other chicken will cause the price for other chicken to fall. Because of the complementary relationship, if the demand for broilers is to be kept constant, the price of broilers must rise.

Similar interpretations can be applied to other estimated cross-price flexibilities. In particular, all the cross-price flexibilities of "other goods" are negative and have relatively larger absolute values than any other flexibilities in each equation. These results indicate strong substitution relationships with meats, and a marginal 1-percent increase in the "other goods" consumption induces a much larger reduction in any given meat price to keep the quantity of meats purchased constant. Although some other cross-price flexibilities may not be consistent with conventional wisdom, these estimates nevertheless reflect the monthly interdependent relationships for various meat cuts that are not explored in other empirical studies.

The middle section of each column in table 1 presents the effects of monthly price shifts on the various meat types. The seasonal shifting pattern of meat prices is similar for commodities in the same category (for example, beef) but significantly different among categories. The seasonal price pattern for beef commodities typically reaches a peak during July-August and decreases sharply in December and again in April. In contrast to beef prices, pork prices typically peak in March and then bottom-out between May-July. Broiler prices peak in July and are lowest in November. Moreover, the estimated autoregressive process, lagged up to 3 months, is significant in all cases. These results are listed at the bottom of each column.

Finally, the statistical modeling in this study combines both the structural equation approach and time series analysis of residuals. The mixed model, which combines the advantages of both approaches, should improve its forecasting ability. To verify the forecasting performance of a model, one may conduct *ex post facto* simulation or may compare the simulated values outside the sample period with actual available data; this study considers the former approach only. Because the observation of a dependent variable is stochastic, even though a model predicts perfectly well its mean value, we

might risk drawing a conclusion of inefficient forecasting if a particular sample point chosen outside the sample period is far away from its mean value. Two *ex post facto* simulations are evaluated; one follows the traditional approach of using the estimated structural model obtained from the estimation in the first step, and the other uses the final results from the estimation of the mixed model. The ratio of the root-mean-square error of forecasts to the sample mean, expressed in percentage terms, is presented in the first two columns of table 2 for each case. In the mixed model, the forecasting errors are less than 1.7 percent of the sample mean and are uniformly lower than the other model. Thus, the forecasting efficiency (shown in the last column of the table) indicates that the mixed model is relatively more efficient for all monthly meat price forecasts. This evidence strongly suggests that the mixed structural-time series model has greater potential for forecasting.

Table 2—Ratio of root mean-square-error to sample mean for meat price forecasts

Commodity	Structural model estimated by OLS (1)	Mixed structure-time series model (2)	Relative efficiency (2)/(1)x100
		Percent	
Sirloin steak	1.43	0.90	62.9
Round steak	1.66	.98	59.2
Chuck roast	2.07	1.30	62.6
Round roast	1.58	.90	57.2
Ground beef	2.07	1.23	59.5
Pork chops	1.56	1.23	78.4
Canned ham	1.80	.80	44.3
Bacon	2.37	1.62	68.4
Sausage	2.15	1.27	59.0
Broilers	1.86	1.31	70.4

Note: The ratio of root mean-square-error to sample mean is calculated by:

$$[\sum_{t=1}^{T} (y_t - \overset{*}{y}_t)^2/T\,]^{1/2} / \bar{y} \times 100,$$

in which y_t is the nominal price in the demand equation, and its predicted value and sample mean are $\overset{*}{y}_t$ and $\bar{y}$, respectively.

Conclusions

I have estimated a set of price-dependent demand equations for highly disaggregated meat commodities, including five beef cuts, four pork items, and broilers. The commodity classifications closely reflect the consumer's demand in the retail market. The equations depict the interrelatedness of monthly demand for meats, an area for which we have limited knowledge and an area that few empirical studies have explored.

All the estimated direct-price flexibilities for these meat commodities are statistically significant and less than 1 in absolute value. The estimated cross-price flexibilities demonstrate a certain economic interdependence for specific meat products and "other goods" in the short run. The significance of estimated cross-price flexibilities emphasizes the importance of interdependent relationships of meat demands and underscores the possible error of ignoring these relationships.

In terms of statistical modeling, a mixed structural-time series model provides both a structural explanation of meat prices and improved forecasting capability. Based on empirical results, the forecasting capability of the model is significantly better than that of the traditional structural equation approach.

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In Earlier Issues

For many types of assets in most manufacturing processes both the salvage value and the use interval are known and the decision-makers have little difficulty in using net investment data to calculate the rate of return needed for proposed investments. For other types of business, particularly single proprietorships, the use interval is uncertain because of the operator's incomplete knowledge of his future willingness or abililty to operate the firm for as long as implied by the specified planning period. In such instances, he needs to form estimates on the value of the asset at interim time intervals because of the possibility that he may cease to operate the firm and that he value of the asset may at that time be subject to test on the market.

Gordon E. Rodewald, Jr., and C.B. Baker
April 1969, Vol. 21, No. 2

Research Review

The U.S. Pork Sector: Changing Structure and Organization

Marvin Hayenga, V. James Rhodes, Jon A. Brandt, and Ronald E. Deiter.
Ames: Iowa State University Press, 1985, 172 pp., $16.50 (paper).

Reviewed by Leland Southard*

On the back cover of their book, the authors state: "...we have attempted to assemble the best available statistical information and economic understanding of the pork sector of our agricultural economy and comprehensively analyze the current organization and behavior of the pork industry, how it is changing and more particularly, why change is occurring, and what its implications are." Thus, Hayenga and others embark on an ambitious effort to answer everything anyone ever wanted to know about the pork sector.

For most analysts who deal daily with hog and pork prices, the chapter on performance is extremely useful because it provides measurements of performance. The appendix summarizes the results of 41 demand studies along with the method of measurement. Anyone doing livestock situation and outlook work should applaud this effort.

The chapter on Government involvement is also worthy of special note. Government activity affects nearly every level of the pork industry. Government actions, such as feed grain policies, are felt indirectly through changes in feed costs. Feed costs relate directly to costs of production. The authors were wise to limit their discussion to major Government activities and not to attempt to comment on each activity. The major activities they discuss include packers and stockyards, animal welfare, futures trading, and health and safety issues. They examine the effects of the recent tax law changes. Their discussion on the use of antibiotics in animal feed is timely because the issue is receiving wide publicity.

Although most writers pick a particular part of the industry to discuss in detail, Hayenga and his colleagues cover everything from the breeding stock supply to the food service industry. The book's 148 pages of text make it more of a handbook than an authoritative reference; however, a suprising number of facts and figures are crammed into those pages. In some instances, the authors only briefly discuss a topic and leave the reader to understand the implications of that particular facet of the pork industry. For example, readers interested in the foreign trade aspects of the pork industry will need another reference.

The book's brevity may occasionally lead the reader to a misunderstanding. For example, "Currently, only 10 States are used for the estimates in the March, June, and September releases, and all States are surveyed for the December release" (p.90). This statement implies that the June report is a 10-State report or that the national estimate is derived from the 10-State data. The June report is national in scope; its data are collected from producers on a national basis, but State estimates are published individually for the 10 States.

In their concluding remarks, the authors state: "pork will continue to suffer important competition from cheaper poultry and more expensive beef." They conclude that feed conversion efficiency and making hogs leaner will largely determine the future of the pork industry.

The authors should be congratulated on pulling together in the same publication material that gives a broad perspective on the U.S. pork industry despite their somewhat exaggerated claims. The book will be useful to market analysts, agricultural teachers, economists, and graduate students trying to gain an understanding of the pork industry.

Anyone interested in the pork industry will find the little time spent reading the book well worth the effort. People who deal every day with the pork industry should add the book to their reference shelf.

*The reviewer is an agricultural economist with the National Economics Division, ERS.

American
Journal of
Agricultural
Economics

Edited by Richard E. Just and Gordon C. Rausser
University of California, Berkeley
Published by the American Agricultural Economics Association

August 1985

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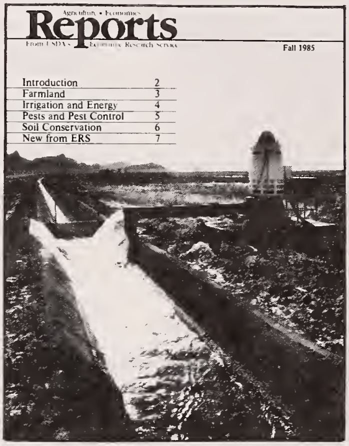

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